Research Article

Historical context, current status and management priorities for introduced Asian house geckos at Ashmore Reef, north-western Australia

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Abstract

The Asian house gecko (*Hemidactylus frenatus*) shows the largest non-native distribution of any gekkonid and has been introduced to numerous oceanic islands around the world. Since 1990, it has been naturalised at Ashmore Reef, a small group of islands, cays and reef flats in the Timor Sea within the maritime borders of Australia. This note provides an updated assessment of its population status and distribution at Ashmore Reef based on surveys conducted in May 2019 and formulates ecological insight to factors that may be influencing the presence of geckos on the islands. In doing so, it aims to provide context relevant to informing suitable future research and management options.

Key words: conservation management, *Hemidactylus frenatus*, island ecosystems, invasive alien species, reptiles, species introductions

Introduction

Human movement around the world has facilitated the accidental and intentional transportation of species outside their native ranges, resulting in many species establishing novel populations (Wilson et al. 2009). A portion of these introduced species have become naturalised in their recipient ecosystems, and a subset of these go on to impact native assemblages and ecosystem processes (Gallardo et al. 2016; Lever 2003). This progression down the "invasion pathway" (sensu Blackburn et al. 2011) is influenced by the interaction between biotic, abiotic and dispersal drivers (Soberón and Nakamura 2009). In turn, depending on the specific context of these features of the recipient ecosystem, the traits of the introduced species, and the chosen frame of reference, the impacts of non-native species can range from negative to neutral to beneficial (Gurevitch and Padilla 2004).

Globally, at least 185 species of reptiles have become naturalised after introductions to areas outside their native range (Lever 2003). However, the

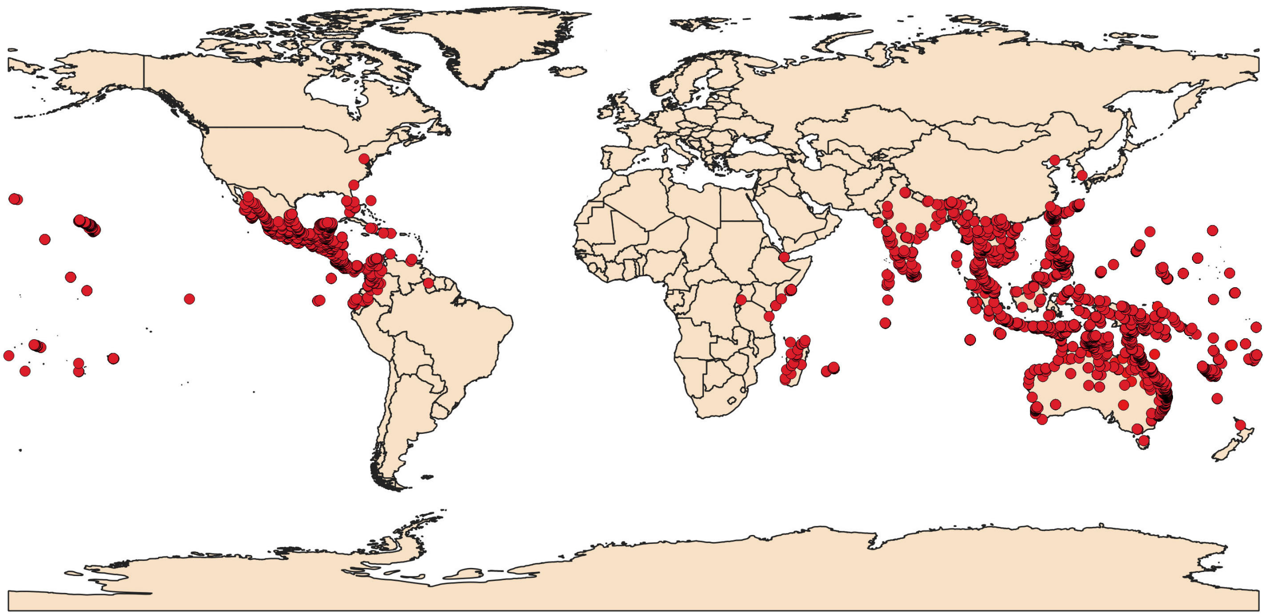

Figure 1. Global distribution of *Hemidactylus frenatus* based on distribution records from Global Biodiversity Information Facility (GBIF) and Atlas of Living Australia (ALA). Data accessed on 5 Nov. 2019.

resulting naturalised population generally remains localised around the point of introduction (Lever 2003; Reed and Kraus 2010). Geckos have proven to be an especially successful group of reptiles with regards to spread to and establishment in new environments. This can be attributed to factors such as their commensal existence with humans, small body size, largely nocturnal habits, calcareous eggs, and high population densities (Kolbe et al. 2016; Locey and Stone 2006; Rödder and Lötters 2009). Among them, the Asian house gecko (*Hemidactylus frenatus* Duméril & Bibron, 1836) is a nocturnal species that has a native range encompassing a wide range of anthropogenic and natural habitats in south and southeast Asia (Lever 2003). This gecko also shows the largest non-native distribution of any gekkonid (Perry et al. 1998; Rödder et al. 2008) with substantial range expansion largely facilitated by humans (Carranza and Arnold 2006; Figure 1).

On the Australian mainland, the Asian house gecko has established through multiple independent introductions since the 1930s, mostly via ship cargo from South-East Asia (Cogger et al. 1983). The species is now known from across northern and eastern Australia (Hoskin 2011; Newbery and Jones 2007; Vanderduys and Kutt 2013), possibly due to post-introduction spread of its own accord, further anthropogenic dispersal, and additional novel introductions. Even after *c.* 90 years, the known populations on the Australian mainland are mostly centred on urban areas and isolated human settlements (Hoskin 2011). The introduction and status of *H. frenatus* on the offshore islands of Australia, especially those that are located far from mainland are poorly known. Smaller islands have been regularly used as shelter, resting places and for food supplies by seafarers for many centuries, and as a consequence a wide range of species have been introduced to these locations. Given the isolated evolutionary history of most island ecosystems, the native biological components of islands are often highly susceptible to the establishment of non-native species (Fordham and Brook 2010; Vilà et al. 2010). Non-native species that can become invasive are the primary driver of extinction and ecosystem change on island ecosystems (Donlan and Wilcox 2008; Towns et al. 2006).

Among Australia's offshore islands, *H. frenatus* is known to have been present at Cocos (Keeling) Islands since the 1930s (Cogger et al. 1983) and at Christmas Island by the 1940s (Gibson-Hill 1947), but little information is available on what the current population status is at these locations (Smith et al. 2012). Ashmore Reef is a small group of islands, sand cays and reef flats in the Timor Sea, within the maritime borders of Australia. It is an internationally significant location for both seabirds and shorebirds (Clarke et al. 2011; Rogers et al. 2011) and a marine biodiversity hotspot (Hale and Butcher 2013; Poore et al. 2015). The only established terrestrial reptile species at Ashmore Reef is *H. frenatus*, although there is a record of an unidentified species of skink from West Island, presumably as a single vagrant specimen (Horner 2005). Storr et al. (1990) first reported the occurrence of *H. frenatus* at Ashmore, but no further information on the species was provided. During a two-week entomological survey of the islands at Ashmore Reef in May 1995, Brown (1999) reported the geckos to be "rare", with only a single individual caught in a malaise trap. They also did not find any specimens among the ground litter while searching for invertebrates. However, during a 16-hr day-time survey in March 2001, Horner (2005) found this species to be "abundant" in all habitat types on West Island, but absent from the two other islands. Based on this evaluation, it was considered to be "well established" on West Island (Hale and Butcher 2013).

No systematic survey or evaluation of the ecological impact of *H. frenatus* on the Ashmore islands have been conducted. However, based on its known impacts on native invertebrates in some parts of its introduced range, *H. frenatus* has been listed as a potential pest species requiring active management at Ashmore Reef (Hale and Butcher 2013; Russell et al. 2004). As an initial step to fill important gaps in ecological knowledge for this introduced population at Ashmore Reef, this note (1) provides an updated assessment of *H. frenatus* population status and distribution, (2) documents ecological insight that may be influencing the presence of the gecko population, and (3) uses niche theory to outline the ecological context relevant to informing appropriate future research priorities and management options.

Materials and methods

Ashmore Reef (12°15′S; 123°00′E), an Australian Marine Park managed by Parks Australia, is a cluster of three vegetated islands (East, Middle, and West Islands) and a vegetated sand cay (Splittgerber Cay) with a total land

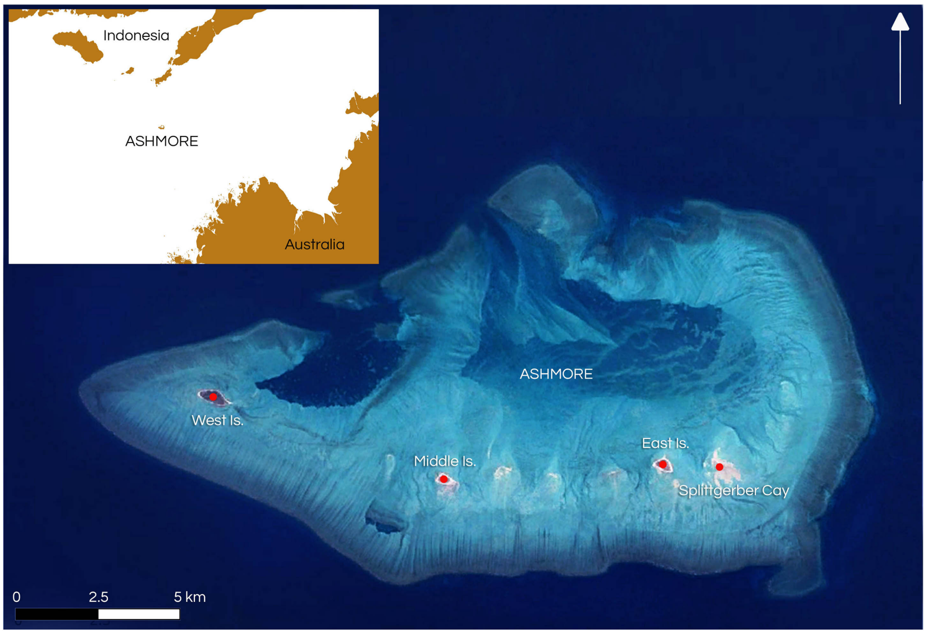

Figure 2. Location of Ashmore (inset) and islands surveyed for *Hemidactylus frenatus* (red dots) at Ashmore Reef Marine Park in May 2019.

area of *c.* 55 ha (Figure 2; Table S1). The islands and associated reefs are situated on the outer edge of the north western continental shelf *c.* 325 km north-west of the Kimberley coast of Western Australia and *c.* 145 km south of the Indonesian island of Roti. Indonesian fishermen have been using the islands as a safe anchorage and supply of freshwater for at least 300 years (Abbott 2006). Since European discovery of the islands in the early 1800s, the islands have undergone phosphate (guano) mining and have been used as a field survey camp for oil and gas exploration in the vicinity.

The islands support a seasonally ephemeral cover of grasses and other low herbaceous and creeping plants. Taller vegetation on West Island is dominated by octopus bush (*Heliotropium foertherianum* Diane & Hilger, 2003), with fish plate shrub (*Guettarda speciose* Linnaeus, 1753), sea trumpet (*Cordia subcordata* Lamarck, 1792), bay cedar (*Suriana maritima* Linnaeus, 1753) and palm trees (*Cocos nucifera* Linnaeus, 1753) described from the three islands over the last three decades (Pike and Leach 1997). Woody plant abundance and cover are influenced by disturbance from turtle and seabird nesting, as well as seed predation. Likely mechanisms for seed removal include hermit crabs and introduced populations of house mice (*Mus musculus* Linnaeus, 1758), the latter restricted to Middle and East Islands (Hodgson et al. 2014; Pike and Leach 1997). Introduced black rats (*Rattus rattus* Linneaus, 1758) were eradicated from West Island in the 1980s. There have been restoration attempts to address the decline of vegetation with limited success (McDonald 2005).

Field surveys for the presence of *H. frenatus* took place in May 2019. To confirm the presence of geckos we conducted targeted visual and auditory encounter surveys during the day and at night on all three islands (Figure 2; Table S1). Walk paths on islands were selected with minimal possible

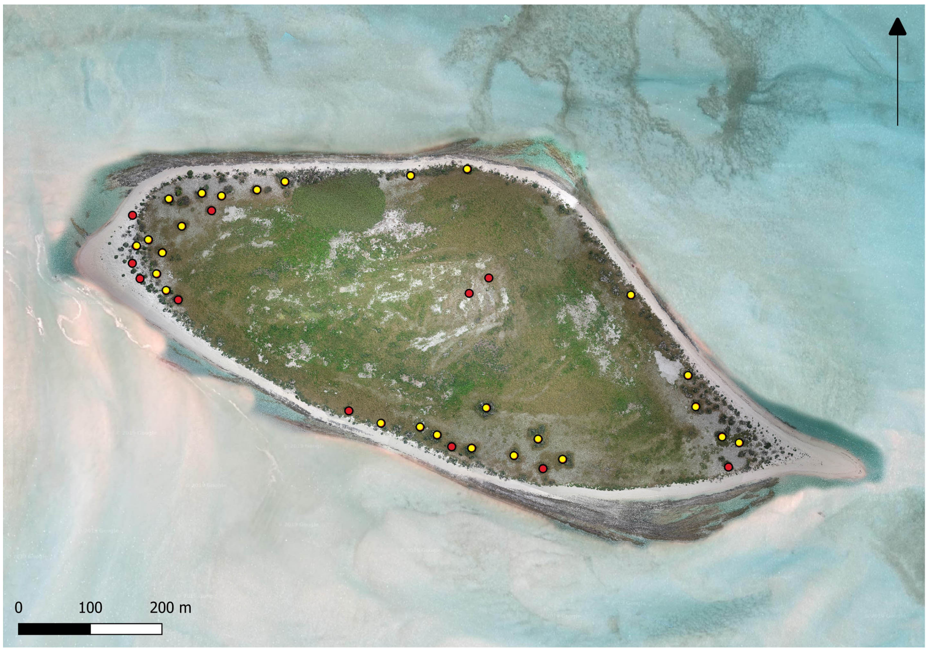

Figure 3. *Heliotropium foertherianum* shrubs at West Island with *Hemidactylus frenatus* present (yellow), and other locations searched but with no geckos recorded (red) in May 2019.

interference to nesting seabirds. Possible daytime retreats and places for shelter, such as under bark on live and dead vegetation, leaf litter under vegetation, under and among driftwood on the beaches, small areas of building rubble associated with old infrastructure, and any larger rocky boulders on land were searched for geckos by 1–2 persons during day time (9:00–11:00: 1 hr at East I. on 3 May, 1 hr at Middle I. on 3 May and 3.5 hrs cumulatively at West I. on 4 and 6 May) and by 2–3 people at night (for 1 hr at Middle I. on 2 May, 2 hrs at East I. on 3 May, 1.5 hrs at West I. on 6 May). Only shrubs with no nesting birds or bird nests on or under them were approached for closer inspection. Because of the intensity of the bird nesting activity, systematic surveys of all shrubs was not attempted. No targeted surveys were conducted at Splittgerber Cay but it was visited and walked for 2 hrs on 3 May during a vegetation survey while opportunistically observing fauna. Where possible, *H. frenatus* were caught, had snout-vent length (SVL) and sex recorded and tail tips were obtained from five individuals for future genetic analyses. All geckos that were hand caught were released at the point of collection soon after processing. We did not conduct trapping as the invasive tropical fire ants (*Solenopsis geminata* Fabricius, 1804) present on the island could have attacked the geckos caught in traps. Field work was conducted under the CSIRO Animal Ethics Committee approval number AEC2019-06.

Results

No geckos were recorded from Middle Island, East Island or Splittgerber Cay. On West Island, geckos were only observed on *H. foertherianum* shrubs mostly along the outer edge of the island (Figure 3; Table S2). Geckos were

Figure 4. Adult female *Hemidactylus frenatus* on *Heliotropium foertherianum* branch *in-situ* at West Island (photo R. Somaweera).

observed to be hiding under bark in both live and dead shrubs during the day time but were active on the branches and main stems of *H. foertherianum* at night (Figure 4). No geckos were observed on or near the ground, including among leaf litter, calcareous beachrock and building rubble in the middle of the West Island, under logs or among driftwood along the shoreline.

Habitat availability varied between islands. The shrub component of the vegetation at Ashmore Reef is largely restricted to a fringing band just inland of the high tide line on West Island. Palm trees on all islands are dead without any fronds, and all but one on West Island had fallen. All shrubs on East Island are now dead, and only one live (but unhealthy) *H. foertherianum* individual remains on Middle Island. Splittgerber Cay does not have any recent history of supporting a shrub layer. All islands and the cay had objects on the ground that could provide shelter, including rocks, lumps of coral, calcareous beachrock, scattered timber (often bamboo), and large tree branches scattered above the tide line and through island interiors. Remnant concrete rubble and infrastructure ruins on East Island and West Island presented further opportunities for shelter at ground level. However, no geckos were found on or under these objects during surveys.

Geckos were observed at 26 of the 35 *H. foertherianum* shrubs sampled at West Island on 4 and 6 May (Figure 3; Table S2). The 89 individuals observed comprised 23 juveniles (< 40 mm SVL) and 66 adults. Of the 14 adults that were hand captured, there were five males and nine females. None of the females were gravid. The SVL of the hand-captured animals ranged from 46 to 67 mm, within the general size range known for the species (Cogger 2014; Greer 2004). Five eggs were observed under bark in live *H. foertherianum* shrubs, as a cluster of four in one shrub and as a single egg in another.

Discussion

Historical context

Exotic species colonize new areas in a three step process: jump dispersal, population establishment, and diffusion dispersal (Locey and Stone 2006). The range expansion of *Hemidactylus frenatus* can be largely attributed to their propensity for jump dispersal. It is a commensal species commonly cohabiting artificial structures, leading to a higher probability of accidental transportation as stowaways with cargo (Dame and Petren 2006; Hoskin 2011). Furthermore, as an arboreal species inhabiting fallen and standing vegetation, the adults or eggs could be washed out to sea with flotsam and subsequently be deposited in new areas (Brown and Alcala 1957; Pianka et al. 2003). The exact time and introduction event of Asian house geckos to Ashmore is not known, but based on Storr et al. (1990), establishment occurred there prior to 1990.

Since at least the late 19th century, Indonesian fishers have been known to regularly and frequently visit the Ashmore Reef islands (Clark 2000). Indonesian ethnic groups including Madurese, Bajau Laut and Butonese sail from small fishing villages throughout Eastern Indonesia to Ashmore, known to them as *Pulau Pasir* (Fox and Sen 2002). Visits by Indonesian vessels to this region in the period 1900–1940 are also well documented (Crawford 1969). These visits by Indonesian vessels resumed after World War II (Serventy 1952). During this period, the islands and the sand cays were well occupied by fishers as they cooked and dried fish and beche de mer, clams and seabirds (Serventy 1952). These observations all demonstrate the historical practice of Indonesian fishers utilising the islands of Ashmore. Therefore, it is possible that stowaway geckos may have been introduced to Ashmore via this pathway at a much earlier date than current records indicate. More recently, vessels used to transport asylum seekers, merchant ships, commercial fishing units from Australia and Indonesia, cruising yachts, charter vessels, and government patrol boats have also accessed the reef and islands at different time periods, providing additional potential pathways for introduction.

Ecological context

The establishment of geckos on West Island may have been facilitated or inhibited by several environmental traits of the island, in combination with behavioural and physiological traits of the geckos. Niche theory allows for the consideration of these factors in a structured way (Soberón and Nakamura 2009), according to abiotic, biotic and movement factors as well as species interactions.

The climate of Ashmore Reef is similar to that of the native range of *H. frenatus* in Asia and well within the range of its broader global distribution (Rödder et al. 2008; Figure 1). The species has broad physiological tolerances, multiple annual breeding cycles (McKay and Phillips 2012), and sperm-retention by females that facilitates reproductive output at any time of the year in the tropics (Yamamoto and Ota 2006) as opposed to seasonally in some subtropical areas (Amey 2013). These traits are likely to have aided establishment and persistence of a population at Ashmore Reef. It appears, therefore, that there are unlikely to be climatic constraints on the persistence or abundance of the *H. frenatus* population. Whether or not the future climate envelope will remain within the species' tolerance is likely to present as a low priority for developing ecological insight, relative to other factors.

Within their introduced range, *H. frenatus* is largely restricted to anthropogenic habitats and natural habitats in their immediate vicinity (Farr 2011; Mckay et al. 2009). At Ashmore Reef, Horner (2005) noted that *H. frenatus* used a wide variety of shelter sites on West Island including shrubs, ground litter, palm fronds, fallen timber and coral rubble. During this study, we only observed geckos on live and standing dead *H. foertherianum* shrubs. A total of 35 *H. foertherianum* shrubs were surveyed in an opportunistic approach on West Island and it is very possible that shrubs not inspected could have had contrasting gecko presence patterns. The coconut trees at Ashmore Reef mentioned by Horner (2005) are now dead, the last tree on West Island dying in 2018 (R.H. Clarke *unpubl. data*). Horner mentioned that multiple *H. frenatus* were usually present when ground litter was moved. One possible explanation for the absence of ground observations could be invasive tropical fire ants that have been known from Ashmore Reef since 1992, which may prevent geckos occupying ground litter. Another possible explanation is the seasonal differences in vegetation condition and ground temperatures during the two surveys, given that Horner's survey was conducted in late wet season in March. If restoration of the shrub layer across the Ashmore Reef islands is considered as a part of future conservation management, it would be important to understand the implications for habitat availability for *H. frenatus*, and whether or not ground habitat preferences are influenced by the presence of *S. geminata*.

Other biotic interactions that may be influencing the presence and abundance of *H. frenatus* relate to food resource availability and predation. The geckos themselves have a broad, non-specialist diet (Iturriaga and Marrero 2013; Tyler 1961), active and effective foraging traits (Frankenberg and Werner 1981), and high efficiency in converting food to energy (Lei and Booth 2014). Food resource availability is, therefore, regarded as a low priority to inform ecological context. House mice are present in Middle and East Islands (Hodgson et al. 2014) and buff-banded rails (*Gallirallus philippensis* Linnaeus, 1766), egrets (*Egretta* spp.), kingfishers (*Todiramphus* spp.) and migrant cuckoos (e.g. *Cuculus* and *Chrysococcyx* spp.) occur on all islands but especially West Island (Clarke and Herrod 2016). These are known predators of small vertebrates such as geckos. However, based on the persistence of geckos over three decades and the current apparent abundance of geckos, it is possible that the predation pressure may not represent a major constraint on presence or abundance of geckos, at least on West Island. In the past, rats were present on West Island, but were eradicated during the late 1980s (Domaschenz 2005) before *H. frenatus* was first observed. The introduced *M. musculus* currently persists on Middle and East Islands, but no geckos have been reported from either island. Whether or not this absence is due to the presence of *M. musculus* or a lack of suitable living space, or perhaps an interaction between the two, is worthy of further investigation to inform the future management of both introduced species.

Lastly, dispersal factors will remain an ongoing management issue for consideration as part of managing *H. frenatus* at Ashmore Reef. Given that Ashmore Reef is a managed Marine Park, visitation to the islands is limited and monitored, therefore risk of new introductions via boat arrivals remains low. That said, the infrequent allowable visitation to the reef by traditional Indonesian fishers, as well as management, research and recreational visitors presents an ongoing invasion risk and should be managed from a biosecurity perspective to avoid further introductions of non-native species. Dispersal to and between islands via flotsam will also remain a risk, and the dynamics of this process would need to be better understood to understand inter-island connectivity.

No population estimates were possible with the available data, given that abundance estimates were not a focus of our study. It is clear from our qualitative data that the species is common on suitable shelter sites on *H. foertherianum* shrubs closer to the shoreline of West Island. The presence of eggs and several hatchlings and juveniles demonstrates active population recruitment. Furthermore, the restricted habitat niche of *H. frenatus* suggests that it would be relatively straight forward to focus a study to quantify abundance.

Prioritising management

While understanding the factors that drive presence and abundance of *H. frenatus* at Ashmore Reef is an important consideration when devising a management plan, whether or not to prioritise the control of *H. frenatus* should focus on likely impacts. Asian house geckos have been introduced to multiple regions in the Americas, Australia, Oceania and Africa outside their native range (Uetz et al. 2019), but known instances of the species causing ecological impacts are limited (Lever 2003). Among the known impacts, the competitive exclusion of sympatric geckos is the most well recognised threat by *H. frenatus* (Case et al. 1994; Cole 2005; Dame and Petren 2006). However, no other gecko or reptile species inhabit Ashmore system, thus competitive exclusion is not a relevant threat in this system. Accordingly transmission of parasites to native species (Barton 2007; Hanley et al. 1995) is also not a possible threat.

A potential pathway to impact by *H. frenatus* at Ashmore Reef is the direct predation of terrestrial invertebrate fauna. Like most geckos, *H. frenatus* is a generalist predator with high foraging efficiency. Arguably, the geckos impose an additional predation pressure on the terrestrial invertebrate communities (Russell et al. 2004) that are already living under harsh environment conditions with a substantial number of avian predators. Terrestrial invertebrates recorded on Ashmore islands include 158 species of insects and 17 other terrestrial arthropods (Brown 2005; Pike 1992). Further assessment on the uniqueness and ecosystem function of these communities would be required to evaluate any impacts from gecko predation.

Across the Pacific Islands, the invasion of forested habitats by Asian house geckos has been patchy and this variation has been attributed to concomitant variation in insect abundance (i.e. a food resource: Petren and Case 1998). While no evaluation of insect abundance across vegetation types at the islands is available, field observations as part of this broader community survey suggests that insects are abundant within the vegetation communities inhabited by geckos. However, at Ashmore, it is possible that the distribution of geckos is governed largely by suitability of shelter sites rather than the abundance of insects.

To prioritise management of *H. frenatus* at Ashmore Reef, we recommend understanding the ecological impacts of the geckos, and specifically prioritising the issue of predation pressure on invertebrates. Analysis of stomach contents of *H. frenatus* and evaluation of any relationship between insect and gecko abundance and insect diversity are recommended as first steps to address gaps in relevant ecological knowledge.

This study builds on that of Horner's study in 2005 (Horner 2005) to provide a contemporary summary of the population status of *H. frenatus* at Ashmore Reef. In doing so, it provides a baseline framework to address ecologically relevant knowledge gaps that may inform appropriate management of this population. The gecko is clearly established and abundant, but has a narrow (and possibly reduced) niche that is likely to be influenced by a range of abiotic, biotic and dispersal factors. Establishing a more comprehensive understanding of the impacts of *H. frenatus* at Ashmore Reef will inform priorities for the management of non-native species within any broader conservation program at this biological hotspot.

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Supplementary material

The following supplementary material is available for this article:

Table S1. Locations of islands at Ashmore Reef visited and surveyed in support of Figure 2.

Table S2. Locations of *Heliotropium foertherianum* shrubs at West Island sampled for *Hemidactylus frenatus* in support of Figure 3.

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